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DEPARTMENT OF THE NAVY

HYDROMECHANICS

STRENGTH OF SILVER-BRAZED PIPE JOINTS
UNDER DYNAMIC LOAD

AERODYNAMICS

by

S. Zilliacus

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April 1965

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STRENGTH OF SILVER-BRAZED PIPE JOINTS
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Report 1972
S-F013 10 01
Task 3974

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ABSTRACT

Destructive dynamic load tests were conducted on specimens of copper-nickel pipe joined to bronze couplings by Grade III silver-braze alloy bonds. The bond areas varied from 9 to 85 percent of the total surfaces available for bonding.

Every failure occurred in the bond. Cracking of the coupling sometimes accompanied bond failure. In no case was there rupture of the pipe. Since many joint failures apparently were influenced by a coupling geometry with abrupt changes in cross section, a modified coupling design is proposed.

The dynamic forces required to produce failure of silver-brazed joints having less than 40 percent bond were considerably smaller than static failure loads in tests conducted elsewhere on similar specimens. For joints with more than about 60 percent bond, the dynamic force values were of the same magnitude as the static loads.

Joints having more than 60 percent bond failed only after considerable elongation of the pipe. For sufficiently great initial dynamic force, joint failure occurred immediately; otherwise two or more loadings were required. Impact velocities associated with joint failures ranged from about 1.6 to about 31 fps.

It appears that the current practice of rejecting joints having less than 60 percent bond is justified for dynamic loading.

ADMINISTRATIVE INFORMATION

These tests were recommended to the Bureau of Ships by letter from the David Taylor Model Basin (Serial 7-392 of 4 October 1963). The work was undertaken as Task 3974 of Project S-F013 10 01.

INTRODUCTION

Dynamic load tests of representative shipboard type silver-brazed pipe connections were conducted at the David Taylor Model Basin after silver-brazed pipe joint bonds had failed in service during shock tests of operating ships. The data indicated that these joints had low bond percentages, that is, the silver-braze bonds covered areas which were small in comparison with the total surfaces available for bonding.

The basic objective of the investigation was to find a relationship between joint strength under dynamic loading and bond percentage.

Two series of tests were carried out. The initial series was designed to determine the dynamic strength of joints (with less than 60 percent bond) similar to those which had failed in service. The later tests were devoted to joints having bonds (63 to 85 percent) covering more than the minimum required¹ proportion of the available bonding area.

A tensile test subjecting the brazed joint between pipe and coupling to a dynamic shear force was arranged. It was expected that this loading would be representative of a severe shipboard shock condition and should provide useful data for determining the dynamic strength of the connection.

To provide a basis for evaluating the strength of the joint, a criterion of performance was required. In consonance with current practice,¹ it was postulated that the bond should not fail; i.e., the bond in a joint must be capable of developing the ultimate strength of the weakest connecting pipe or fitting.

DESCRIPTION OF TESTS

DROP VEHICLE

A drop vehicle was constructed specifically for these tests. Specimens were prepared for testing by the attachment of two retaining flanges. One flange was attached to a weight, the other to the removable top of the vehicle. The assembly was lowered into the vehicle and the top bolted down; details of the test arrangement are given in Figures 1 and 2. Sufficient clearance was provided below the suspended weight to preclude its contact with the bottom of the test vehicle while the specimen was intact.

For each test, the drop vehicle was raised a known distance and dropped onto an impact plate by tripping an electric release mechanism (Figure 2). Upon impact, the specimen was subjected to a tensile dynamic force equal to the product of the suspended mass and its acceleration. The dynamic tensile force in the pipe was transferred into the coupling primarily by means of shearing force in the bond. If joint failure did not occur, the suspended mass oscillated with a characteristic frequency which depended mainly on the stiffness of the specimen and the magnitude of the suspended mass, since the vehicle was several times heavier and stiffer than the weighted specimen.

TEST SPECIMENS

The Mare Island Naval Shipyard, which had been fabricating similar specimens for a series of static strength tests,² furnished 33 specimens together with information on the percentage of bond in each joint. The specimens consisted of 70-30 copper-nickel pipe³ and bronze couplings^{4, 5} joined with Grade III silver-braze alloy.⁶

¹References are listed on page 27.

Nineteen 1-in. and eight 3-in. specimens were tested to destruction. Geometric data on the specimens are given in Table 1. The bond percentage of each joint, as determined by ultrasonic inspection at Mare Island Naval Shipyard, is shown in Table 2.

INSTRUMENTATION

Instrumentation consisted of an unbonded strain gage accelerometer attached to the lower flange (Figure 1) and, in some cases, tensile and bending strain gages attached at the centers of the pipe sections and the couplings. The gages were powered by a carrier amplifier which also amplified the output signals from the gages. A recording oscillograph provided display of the output signal. A signal from a tuning fork oscillator was used as a time reference.

The recording system had an essentially flat frequency response from direct current to 700 cps, and the natural fundamental frequency of a specimen as suspended was about 300 cps. The drop test vehicle was designed to have a frequency several times greater than that of the weighted specimen.

TEST RESULTS

Bond failure occurred in each specimen tested to destruction. There were no pipe ruptures, but cracking of the coupling did occur in five specimens. When the magnitude of the dynamic force was made sufficiently great, joints failed during the first loading. Otherwise two or more force applications were required for joint separation. In some cases, repeated application of approximately equal forces resulted in bond failure.

For the initial series of tests (joints with less than about 60 percent bond), permanent axial deformation of less than about 2 percent occurred in the pipe sections. For the second series (joints with more than about 60 percent bond), permanent pipe strains of up to about 10 percent axial and about 4 percent circumferential took place and were accompanied by permanent circumferential coupling strains of up to about 3 percent. The circumferential "flaring out" of the coupling was accompanied in five cases by cracking at the reentrant corner in the shoulder; see Figure 3.

A representative oscillograph record from a drop test, giving acceleration of the lower flange, and both tensile and bending strain in the pipe is shown in Figure 4. As expected, acceleration and tensile strain time histories are similar in shape and are in phase. Permanent elongation of the pipe is indicated by the zero shift in the tensile strain record. There was also permanent deformation due to bending, indicating yielding in the pipe to relieve the eccentricity of the specimen.

*Four 1-in. and two 3-in. specimens were not tested to destruction because pipe ends slipped excessively in the retaining flanges, thus reducing the forces experienced by the joints.

Table 2 gives the height of drop, peak acceleration and duration, dynamic load, and other pertinent values for each drop test.

To present the data from 1-in. and 3-in. specimens together, plots were made using tensile stress in the pipe as the ordinates and ultrasonically obtained bond percentages as the abscissae. Figures 5, 6, and 7 give stress in the pipe at failure of the joint, during the first drop, and when it reaches its maximum value, respectively. Included for comparison in Figure 5 are static test data,² which are also listed in Table 3.

Representative values of impact and rebound velocities of the drop vehicle are shown in Figure 8. The maximum impact velocities required to cause failure were about 10 fps for joints having less than 60 percent bond and about 31 fps for joints having more than 60 percent bond.

Finally, the plastic strain energy per unit volume absorbed by the highly ductile pipe sections has been plotted against the percentage of bond in Figure 9, together with comparative static test data.² The strain energy was obtained by integration of the area under a stress-strain curve (Figure 10).

As a check on the ultrasonic measurements,¹ a visual estimate was made of the bond areas of selected specimens after the joints had failed. Table 4 gives ultrasonically and visually obtained bond percentages for comparison.

Each specimen was divided into "parts" consisting of the clear length of pipe between flanges, socket of coupling plus braze metal and pipe included therein, and the barrel (remainder) of the coupling. The approximate relationships among the flexibilities of the "parts" of the specimens were calculated and are given in Tables 5 and 6.

DISCUSSION OF RESULTS

PERMANENT STRAINS

The drop tests induced several types of permanent deformation, namely, bending, axial, and circumferential. The effect of bending did not appear to reduce significantly the ultimate dynamic strength of any specimens. Since the pipe material is quite ductile, the pipe simply relieved itself, by yielding, of any eccentricity in the specimen.

On the other hand, large permanent axial tensile strain in the pipe was significant, giving rise to considerable circumferential shrinkage or "necking down" which extended to the coupling, where the abrupt change in section caused a severe strain discontinuity; see Figure 3. While "necking down" of the pipe was taking place, the coupling socket was experiencing permanent circumferential tensile strains, i.e., "flaring out," due to the eccentric "lap-joint" action of the brazed connection. "Necking down" of the pipe together with "flaring out" of the coupling probably caused considerable tensile stress between pipe and coupling at the abrupt change in section. Thus, failure may have occurred due to tensile and shear stresses acting in combination.

Thus it may be seen that undesirable geometry of the couplings (and of other similar cast fittings)⁵ probably reduces the strength of brazed joints. A revised coupling configuration which lacks some of the deficiencies present in the existing design is shown in Figure 11 and includes the following changes:

1. Rounding all reentrant corners to decrease stress concentrations.
2. Increasing the thickness of the socket to prevent its "flaring out."
3. Removing material at the end of the socket to provide for a more gradual change in cross section between pipe and coupling.

STRESS IN PIPE AT JOINT FAILURE

Since the ratios of pipe and coupling sectional areas to 100 percent bond areas are about the same for 1-in. and 3-in. pipe (Table 1), use of stress in the pipe as a variable in Figures 5, 6, and 7 is justified.

The data of Figure 5 indicate that for joints having bonds of less than 40 percent, the dynamic force required to produce failure was generally much smaller (often by 50 percent) than the static force.² Also, the 3-in. specimens failed at a lower static and dynamic tensile stress in the pipe than did the 1-in. specimens.

For joints having more than about 60 percent bond, the dynamic forces required to produce failure were of the same magnitude as the static. The 3-in. specimens failed at a lower static tensile stress than the 1-in. specimens. The dynamic stress values showed about the same scatter as the static values and fluctuated essentially within the extremes of the latter.

Pipe stresses due to initial drops are given in Figure 6, and the maximum values attained are plotted in Figure 7. An examination of Table 2 and Figures 5 through 7 lead to the following observations:

1. The influence of a large number of repeated loads on joint strength decreases as the percentage of bond is increased. For example, Joint 1-1, with 20 percent bond, withstood 10 drops at pipe stresses of about 10,000 psi and then 18 drops at about 32,000 psi. Failure occurred as a result of the 29th drop at a pipe stress of only 12,000 psi. On the other hand, Joint 1-116, with 82 percent bond, underwent 50 drops at pipe stresses which gradually increased from about 22,000 to about 37,000 psi. The drop height was increased for the 51st drop, resulting in joint failure at a pipe stress of about 56,000 psi. Thus, a joint with 20 percent bond failed after 29 drops whereas a joint with 82 percent bond apparently remained undamaged after 50 drops at greater forces.

2. In some cases, there is a decrease in the developed dynamic force after only a few successive identical drops, evidencing progressive bond failure in the joint. There is an increase in other cases, indicating strain hardening of the (initially very ductile) pipe. In Joint 1-3, for example, the pipe stress decreases from about 18,000 to about 9000 p-si during three 1-in. drops whereas in Joint 1-22, there is an indication of an increase from about 28,000 to about 30,000 psi during four 2-in. drops.

3. A roughly linear relationship exists between the upper bound of tensile stress in the pipe and the percentage of bond.

4. The best straight line fit to the data of either Figure 5 or 7 would not pass through the origin. This phenomenon probably results from the omission in the bond percentage determination of the braze metal in the insert ring groove, at the extreme end of the pipe, and in the fillet at the juncture of pipe and coupling; see Figure 3.

The scatter among the points in Figures 5, 6, and 7 can probably be explained as follows:

1. Undoubtedly the greatest cause of scatter is the lack of uniformity of the tests in number and magnitude of load applications and, although perhaps less importantly, in specimen geometry.

2. Possible variation in joint quality and errors in measurement of percentage of bond. It may be seen in Table 4 that agreement between visual and ultrasonic percentage of bond is much better for the second series of specimens than for the first. It would appear that ultrasonic techniques are improving and/or that higher bond percentages (over 60) are easier to determine accurately.

3. Errors due to limitations of instrumentation. These are not much more than ± 5 percent.

4. Errors of data reduction. No greater than those of Item 3.

It may be noted that the test results have not been presented in terms of average shear stress in the silver-brazed joint. The average shear stress can be obtained by dividing the measured dynamic load acting on a joint by its bond area. A plot of bond shear stress versus percent bond would appear to show that the shear stress which a joint can endure decreases with increasing percent bond rather than being constant at failure, for both static⁷ and dynamic loading. Thus the most important relationship, namely, that the load which a joint can support increases with percent bond, would be distorted.

IMPACT AND REBOUND VELOCITIES

After initial collision with the impact plate, the drop test vehicle rebounded several times. Measurements of the time intervals between successive impacts of the vehicle showed the magnitudes of its rebound velocities to be up to about 60 percent of the initial impact velocities. Therefore the magnitude of the total change in velocity of the vehicle was up to about 1.6 times that of the initial impact velocity. Representative values of drop heights and associated rebound velocities of the vehicle are given in Figure 8. These data indicate that the total velocity change varied from up to about 2.5 to a maximum of about 33 fps whereas the drop velocities ranged from about 1.6 to about 31 fps. When the impact velocity exceeded about 16 fps, the rebound velocity was greatly reduced. This phenomenon probably resulted from the conversion of most of the kinetic energy of the drop vehicle into plastic strain energy in the impact plate and the vehicle.

For joints having less than 60 percent bond, the maximum impact velocity and change in velocity required to produce bond failure were about 10 and 16 fps, respectively. Thus all these failures were caused by velocities not significantly greater than the capacity of high impact shock machines.

For joints having more than 60 percent bond, the maximum impact velocity and change in velocity required for bond failure were about 31 and 33 fps, respectively.

PLASTIC STRAIN ENERGY IN PIPE

The plastic strain energy absorbed by the pipe per unit volume was obtained as follows: First, measured dynamic plastic stress-strain data were compared with static data (Figure 10) for the pipe and found to agree fairly well. Next, the inelastic part of the area under the static stress-strain curve corresponding to a particular dynamic load was computed. This area represented the plastic unit strain energy for the pipe and was plotted against percentage of bond in Figure 9 together with similarly obtained energy from static tests.² Examination of Figure 9 discloses the following:

1. For bond percentage between 60 and 80, the energy per unit volume appears to be independent of percent bond.
2. For a given unit energy, a statically tested joint with only about 45 percent bond was equivalent to a dynamically tested joint with about 70 percent bond.
3. The 3-in. pipes are capable of absorbing far less plastic unit energy, generally, than are the 1-in. pipes.

The flexibility relationships of Tables 5 and 6 have been included to indicate which "part" of a given specimen tends to absorb the most elastic strain energy, this absorption being directly proportional to flexibility. Since the coupling flexibility remains constant and the joint flexibility varies but little for a given pipe diameter, the proportion of the total elastic strain energy absorbed by the pipe is primarily a function of its length.

But in these tests, the pipes underwent a great deal of axial plastic deformation. Why, then, is the elastic flexibility of interest? The answer is that the initial (elastic) deformation of the pipe determined the subsequent course of events -- the highly ductile pipe merely continued to deform plastically after yielding had begun, attracting to itself the major part of the energy imparted to the specimen.

A reduction in length of the pipe sections led, as may be seen in Table 6, to an increase in the relative flexibilities of the couplings and the joints. That this change, in turn, caused the joint to absorb a greater proportion of the total energy is indicated by the inability of the shorter specimens to survive repeated loading. Three of four specimens which failed as a result of one drop were short specimens, ranging in length from 20 to 60 percent of that of the usual specimens; see Table 2 and Figure 6.

In general, the flexibility of the joint relative to the total flexibility of the 3-in. specimens was between about 2 and 3 times greater than that of the 1-in. specimens. Therefore, it might be argued that the 3-in. joint absorbs a greater proportion of the total strain energy available to the specimen than does the 1-in. joint. The relatively low values of energy absorbed by the 3-in. pipes up to failure of the joint (Figure 9) may be interpreted to support this contention.

From the preceding discussion of plastic strain energy, the following observations can be made:

1. In an acceptable joint¹ (one having at least 60 percent bond), there is no increase in resistance to repeated loading with an increase in bond percentage.
2. Repeated static loads appear to be less injurious than repeated dynamic loads.
3. Repeated loads appear to be more injurious to 3-in. than to 1-in. joints.
4. In a shipboard pipe system, the ductile pipe serves as an energy absorber, deforming (plastically when shock input is sufficiently great) without being damaged. The greater the pipe length between a fitting and the imposed shock motion, the smaller is the probability of joint failure.

POSSIBLE EFFECTS OF BENDING AND INTERNAL PRESSURE

In a shipboard pipe installation, both bending and internal pressure can be present together with axial tensile dynamic loading. In a long span of pipe subjected to bending, pipe yield would prevent significant bond shear stresses from developing in joints in the span. However, large joint shear stresses might be encountered in short spans subjected to bending, i.e. changes of direction (at elbows, tees, crosses, etc.), and at points where fittings are subjected to impact. The tests described in this report were tensile, not bending. But since shear stress in the joint can be produced equally well by either tensile or bending loads, it is believed that the tests were realistic. Internal pressure, which was not present in these tests, would cause circumferential tensile stress (25 and 39 percent of minimum required yield strength in the 1- and 3-in. pipes, respectively, for the design pressure of 700 psi) and axial tensile stress about half as great in the pipe. The net result might be to decrease the dynamic load required for joint failure.

In the case of explosion attack against a ship it can be argued that internal pressure is relatively unimportant in failures of valves and hull fittings, and that the important factor is the mechanical shock associated with the motions of the hull as induced by the explosion shock wave. It appears likely that the same conclusion would apply to the pipe couplings discussed in this report. Hence, a mechanical test without superimposed internal pressure should serve as a good index of joint strength.

CONCLUSIONS

The following conclusions for silver-brazed pipe and fitting connections are based on data from destructive dynamic tensile tests of copper-nickel pipe³ and bronze coupling specimens.^{4, 5}

1. Joint failure always occurs in the bond.
2. The dynamic strength of a silver-brazed joint is:
 - a. Considerably less than its static strength when bond percentage is less than 60.
 - b. On a par with its static strength when bond percentage is greater than 60.
3. When the bond percentage is greater than about 60, cracking of the fitting can accompany the bond failure.
4. Cast bronze fittings have undesirable design features, namely, abrupt changes in sectional area and sharp reentrant corners which probably reduce joint strength. These deficiencies could be remedied.

5. The indices associated with failures of joints having less than 60 percent bond are:
 - a. Bond failures occur at velocity changes lying within the range capacity of high impact shock machines.
 - b. Permanent axial pipe strains of up to about 3 percent accompany bond failure. Permanent strains in the fitting are negligible.
 - c. Failure results from shear stress in the bond.
6. For bond percentages above 60, joint failures are associated with the following indices:
 - a. Velocity changes as great as 33 fps are required to produce bond failure.
 - b. Bond failures are accompanied by permanent axial tensile strains in the pipe of up to about 10 percent and permanent circumferential tensile strains in the fitting of up to about 3 percent.
 - c. Bond failures apparently result from combined shear and tensile stresses.
7. Depending primarily on the magnitude of the dynamic load, the following types of failure, listed in order of decreasing magnitude of dynamic load, can be expected:
 - a. The bond fails immediately as a result of the first load.
 - b. The bond fails suddenly, after having survived several dynamic loads, or gradually, while being subjected to repeated loads.
 - c. The pipe, which is very ductile, is capable of absorbing a large quantity of plastic strain energy, thereby protecting the joint from failure.

RECOMMENDATIONS

1. The current practice² of rejecting joints with less than 60 percent bond should be continued.
2. Since the type of test described in this report is effective in evaluating the dynamic strength of a brazed joint, it is suggested that its use be considered for testing other types of pipe connections such as welded joints.
3. The geometric design deficiencies of cast bronze fittings should be overcome. An alternative coupling design having rounded reentrant corners and gradually changing sectional area is shown in Figure 11. The changes proposed in Figure 11 are equally applicable to all similar cast fittings.⁵

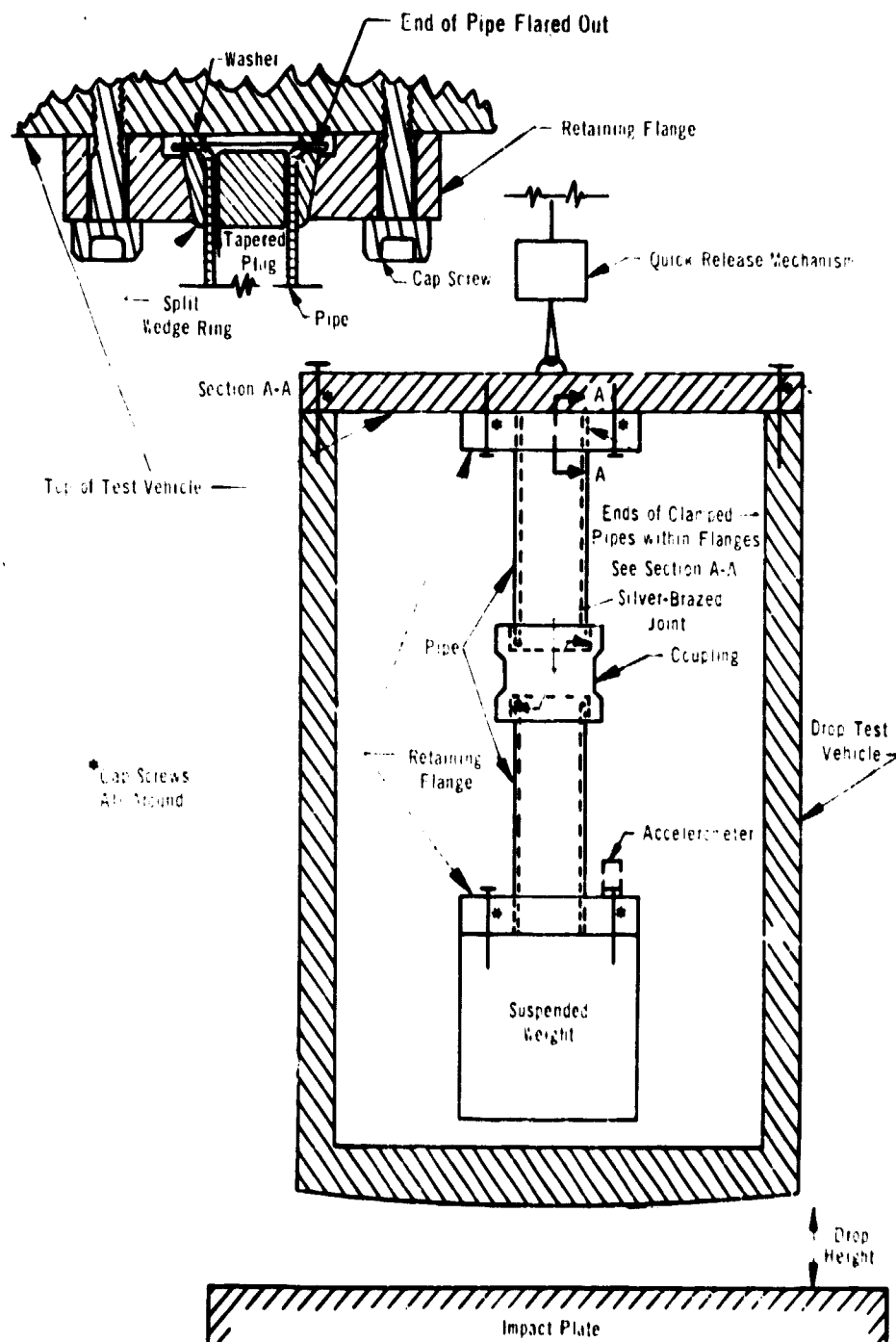


Figure 1 - Section of Drop Test Vehicle

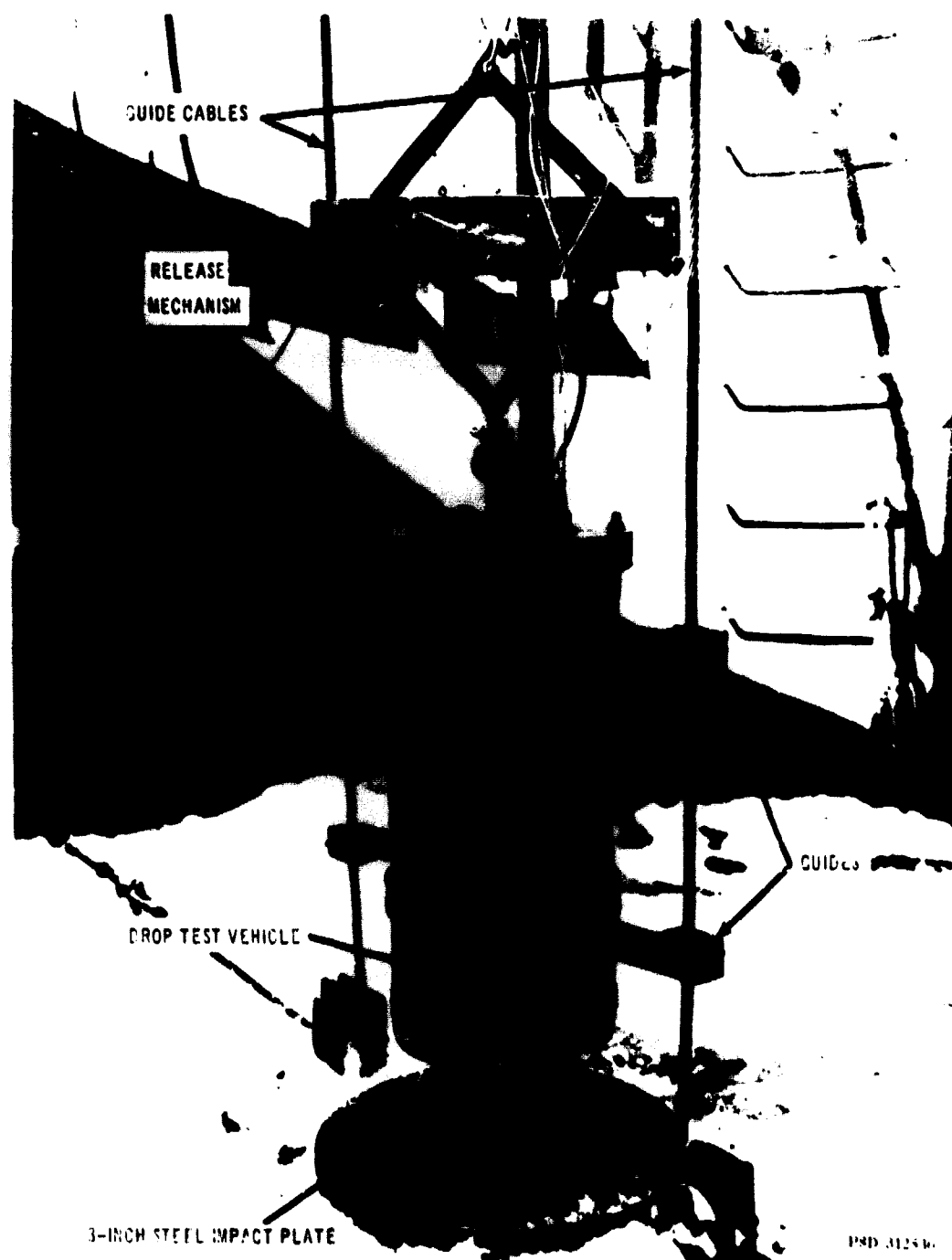


Figure 2 - Drop Test Vehicle Ready for Release

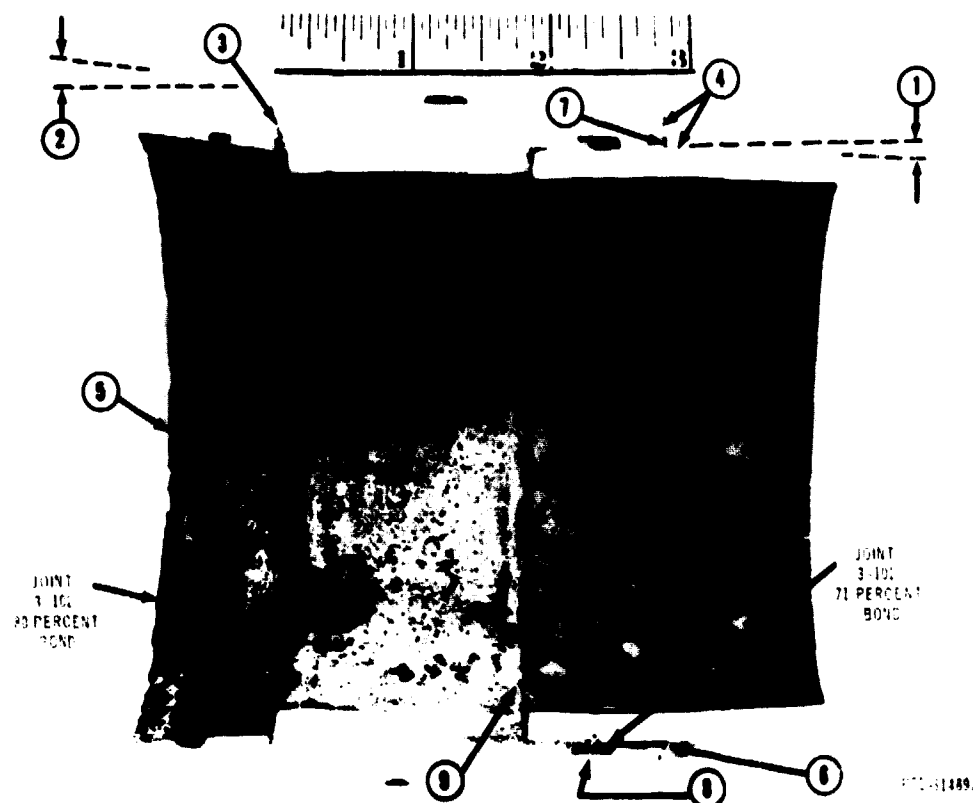


Figure 3 - Failed 3-Inch Specimen
 Joint Numbers 3-101 and 3-102 were sawed longitudinally.

- ① Necking down of pipe
- ② Flaring out of coupling mouth
- ③ Cracking of coupling at reentrant corner of shoulder
- ④ Abrupt change in cross section at juncture of pipe and coupling
- ⑤ Complete bond failure
- ⑥ Incomplete bond failure
- ⑦ Extra bond area - fillet
- ⑧ Extra bond area in brass metal groove
- ⑨ Extra bond area at end of pipe

SPECIMEN 1-7 AND 1-8. DROP NO. 5 (2.5 IN)

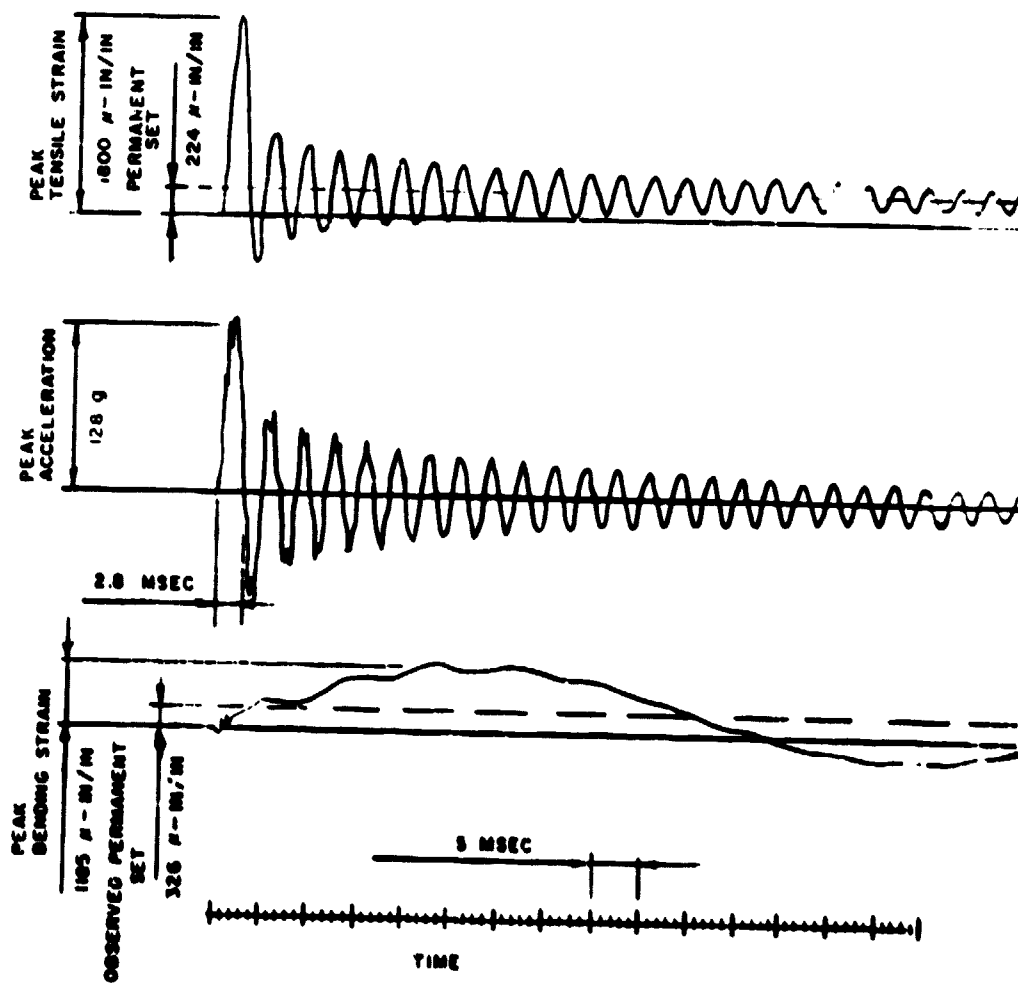


Figure 4 - Typical Record of Tensile Strain, Acceleration, and Bending Strain

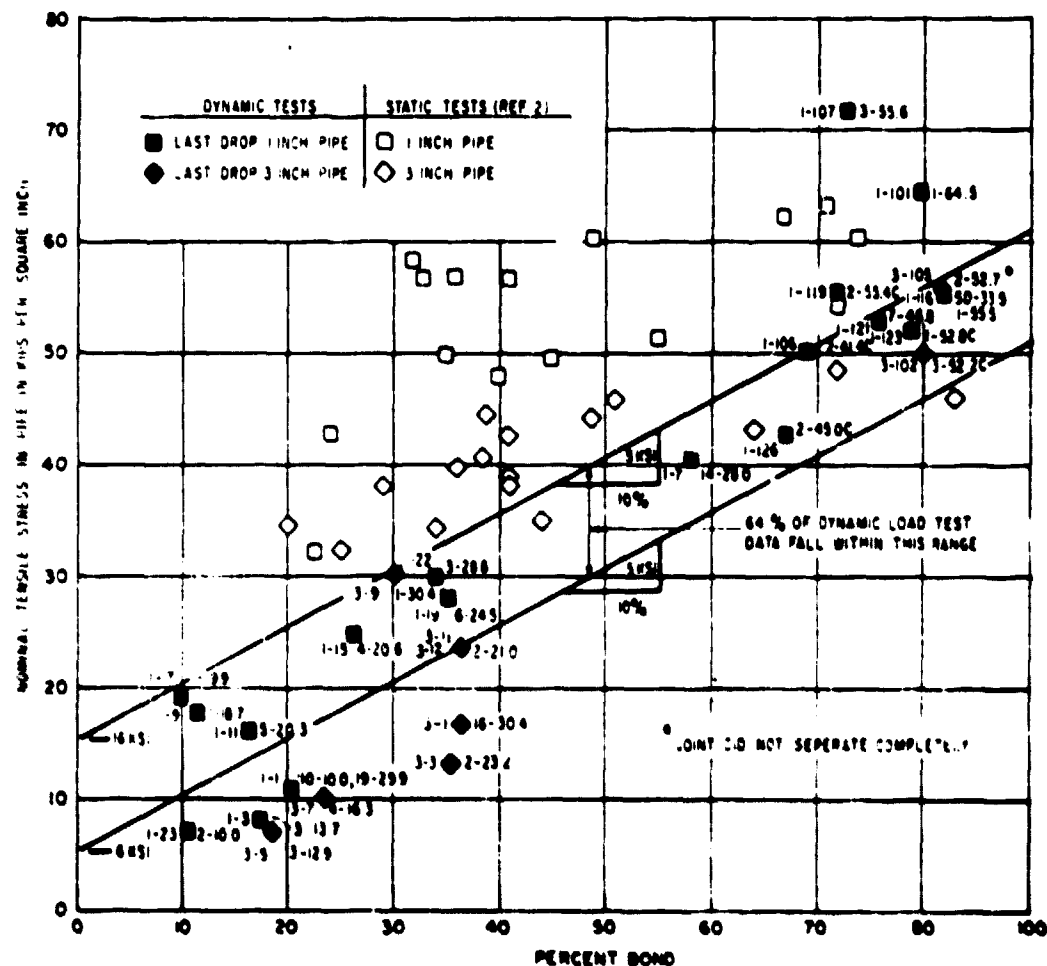
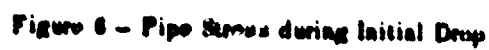


Figure 5 - Pipe Stress at Bond Failure

- Notes:
1. Number to the left of symbol indicates which joint failed.
 2. Numbers to the right of symbol indicate how many drops were made and the mean stress for the drops. Thus 3-58 means three drops, the average stress for the three being 58 ksi.
 3. The letter "C" indicates cracking of coupling.
 4. The two parallel lines are for comparisons among Figures 4 through 7.



2. Joint number is shown below symbol.

1. The two parallel lines are for comparisons among Figures 3 through 7.

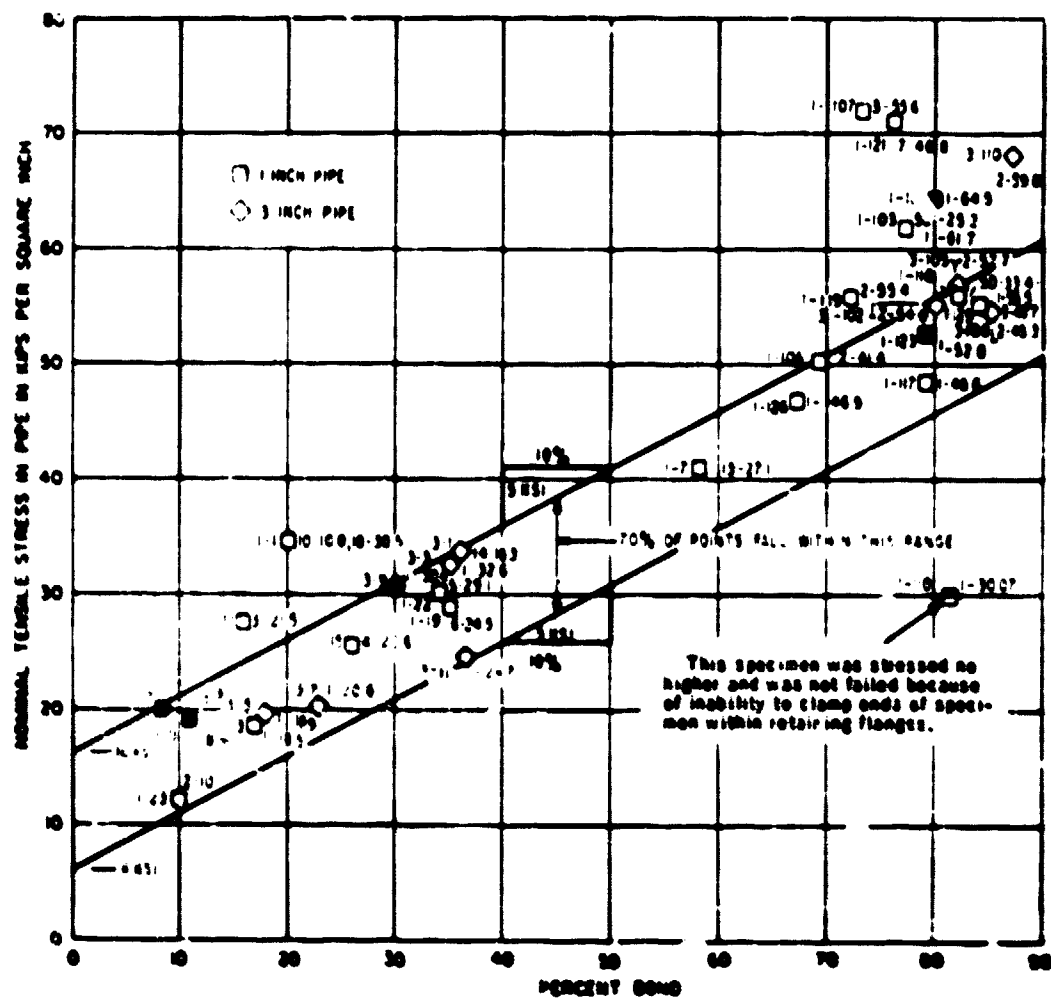


Figure 7 - Maximum Value of Pipe Stress

- Notes:
1. Solid symbols are first drop failures.
 2. Number to the left of symbol indicates the point that failed.
 3. Numbers to the right indicate how many drops were made and the mean stress of the drops.
 4. The two parallel lines are for comparison among Figures 5 through 7.

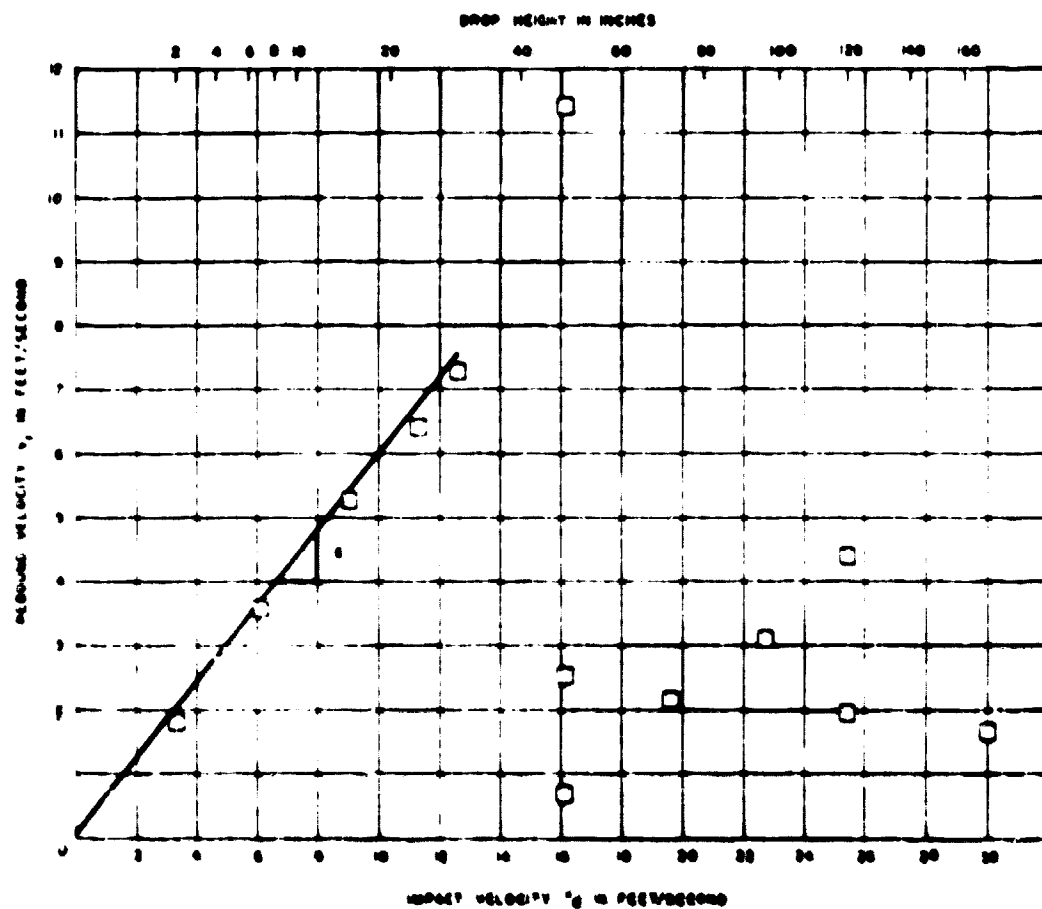


Figure 8 - Rebound Velocity versus Impact Velocity of Drop Test Vehicle

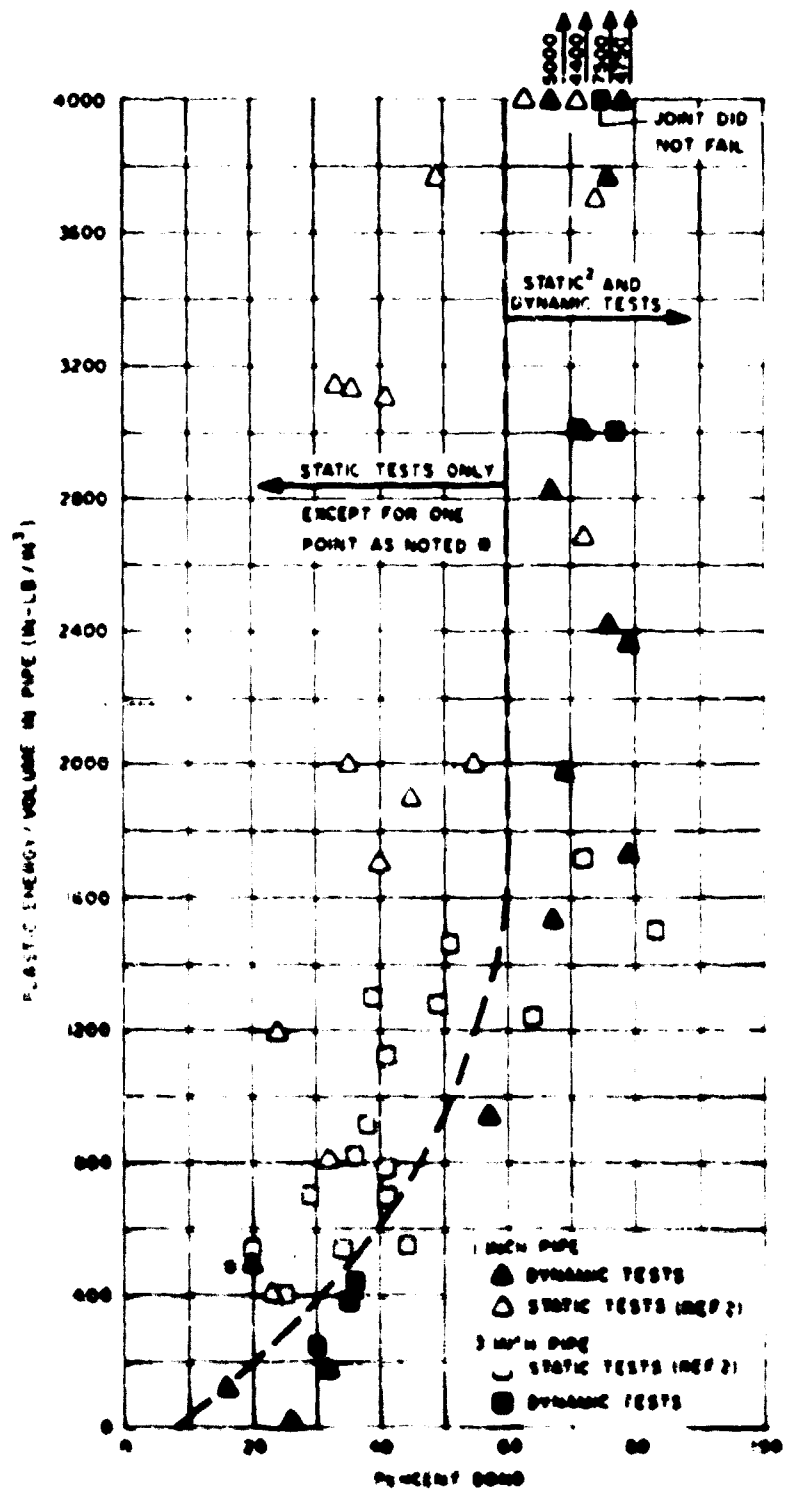


Figure 9 - Plastic Strain Energy per Unit Volume in Pipe at Joint Failure

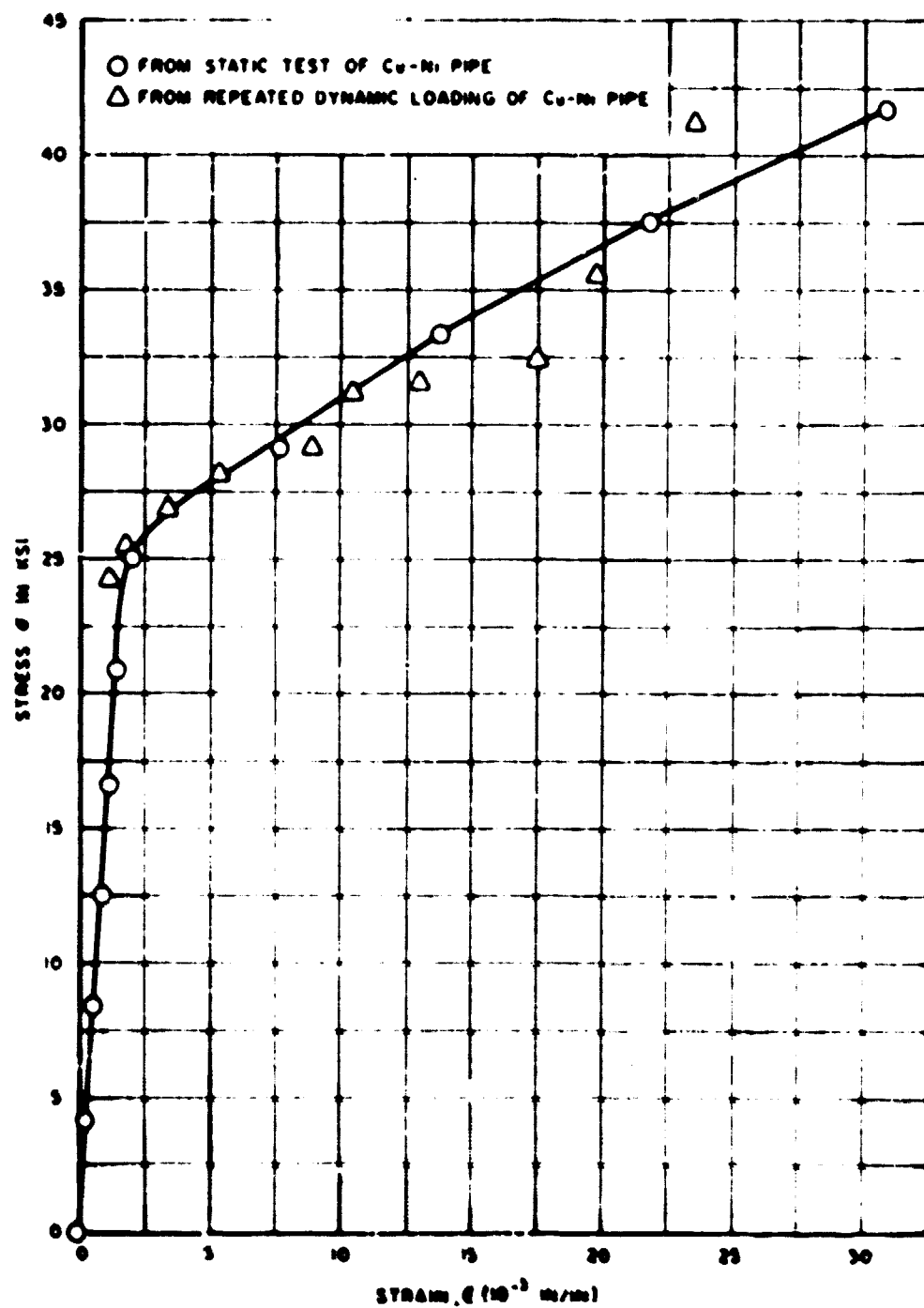
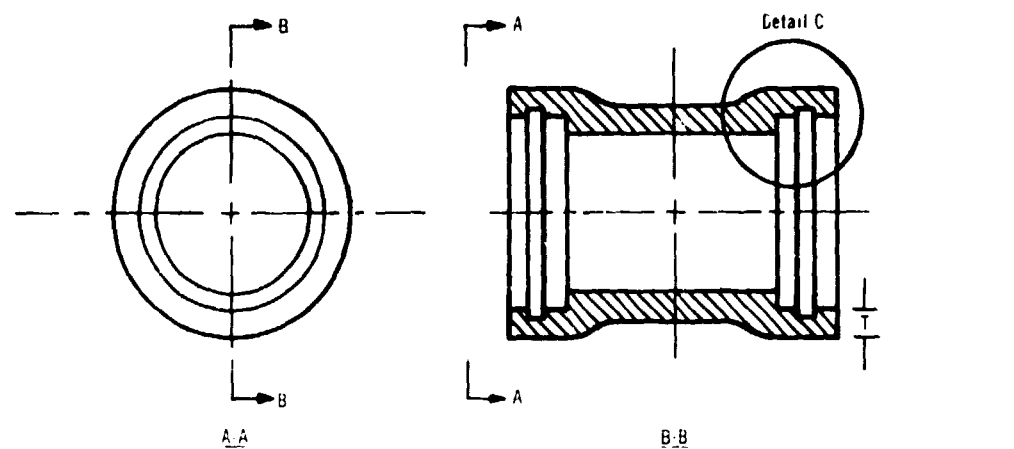
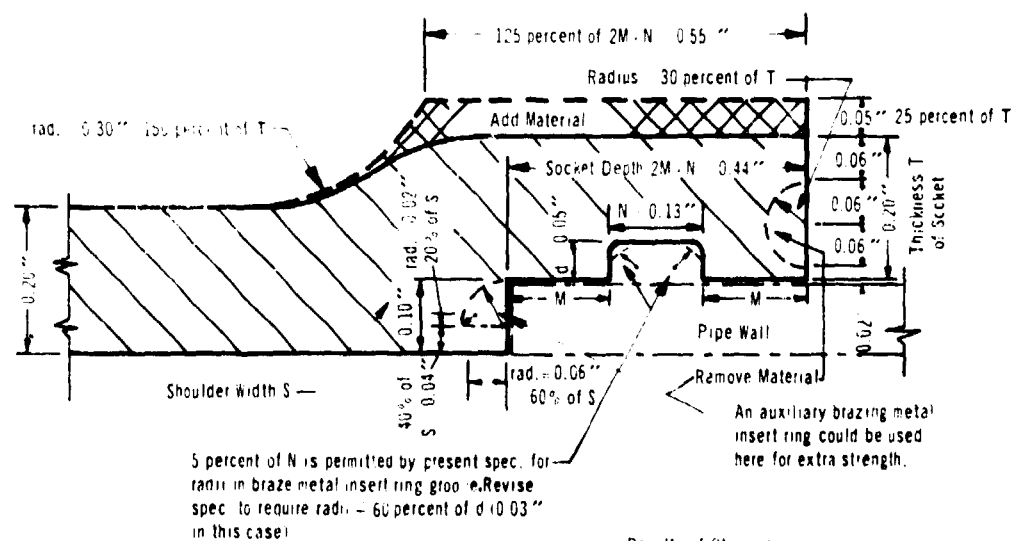


Figure 10 - Stress-Strain Data for Copper-Nickel Pipe from Static and Dynamic Tests



1-in. coupling per Ref. 5



Detail C
Scale 0.2" = 1.0"

Results of Changes

1. Increase in weight of coupling ~ 17%
2. Increase in maximum diameter of coupling ~ 6%

Figure 11 — Proposed Coupling Design Changes

A 1-in. coupling has been chosen for purposes of illustration. The changes are applicable to other similar fittings, viz., elbows, crosses, and tees.

TABLE 1

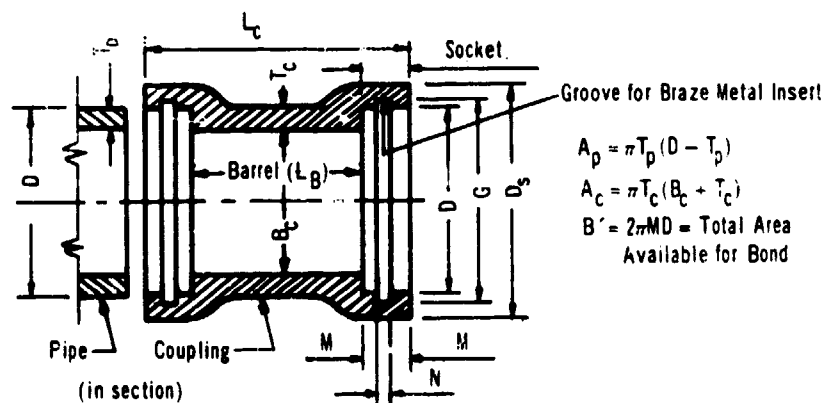
Dimensions and Areas of Pipe and Couplings

Pipe Size in.	Pipe Outside Diameter (max) D in.	Thickness		Coupling		Socket Diameter		Land Width M in.	Groove	
		Pipe (min) T _p in.	Coupling (min) T _c in.	Bore B _c in.	Length L _c in.	Outside (min) D _s in.	Inside (min) D in.		Diameter G in.	Width N in.
1	1.315	0.095	0.20	1.108	2.38	1.72	1.315	0.154	1.424	0.130
3	3.500	0.165	0.35	3.178	3.18	4.20	3.500	0.287	3.613	0.55

Dimensions of Pipe* and Couplings**

Pipe Size in.	Pipe Sectional Area A _p sq in.	Coupling Barrel Sectional Area A _c sq in.	100 Percent Bond Surface Area B' sq in.	A _p :A _c :B'
1	0.36	0.82	1.27	1:2.3:3.5
3	1.73	3.88	6.31	1:2.2:3.6

Areas of Pipe and Couplings



*Dimensions are from Reference 3.

**Dimensions are from Reference 5.

TABLE 2
Test Results

[illegible]

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TABLE 3
Pipe Loads at Bond Failure - Static Test Data*

1-Inch Pipe			3-Inch Pipe		
Percent Bond (Ultrasonic Inspection)	Ultimate Tensile Force kip	Ultimate Tensile Stress in Pipe kip/in ²	Percent Bond (Ultrasonic Inspection)	Ultimate Tensile Force kip	Ultimate Tensile Stress in Pipe kip/in ²
27	11.6	32.6	20	60.5	35.0
24	15.7	43.6	25	52.0	32.9
			29	67.0	38.7
32	18.3	50.8			
37	20.7	57.5	34	66.5	35.0
35	18.2	51.5	36	64.5	40.2
36	20.7	57.5	38	71.0	41.9
			39	78.0	45.1
40	17.5	48.6	41	67.0	38.7
42	20.6	57.2	41	68.0	39.3
			41	74.5	43.1
			44	61.5	36.5
45	18.0	50.0	46	77.0	44.5
46	21.9	60.7	51	80.0	46.0
48	18.6	51.3	64	75.0	43.4
49	22.5	62.3			
50	21.9	60.6			
51	19.8	54.4	72	84.5	48.6
54	23.8	66.5	80	86.5	49.0

*Steel Reinforcement

TABLE 4
Comparison of Ultrasonically and Visually Obtained Bond Percentage

Edges		Percent Bond		Difference V-U	Discrepancy $\frac{V-U}{U}$
Size	Number	Ultrasonic U	Visual V		
1	1-3	17	33	+16	+94
	1-19	35	31	-4	-11
	1-3	10	13	+3	+30
2	1-3	35	27	-8	-23
	1-5	16	17	+1	+6
3	1-1-1	80	75	-5	-6
	1-11-6	82	81	-1	-1
	1-1-3	79	82	+3	+4
	1-1-0	67	76	+9	+13
4	1-1-2	6	82	+76	+125

TABLE 5
Flexibilities of "Parts" of Specimens

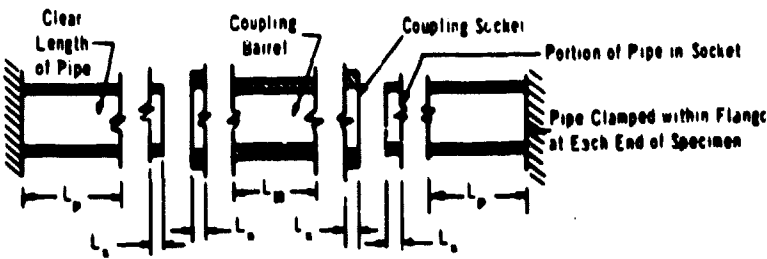
Characteristic	Pipe Size	Pipe	Coupling Barrel	Joint
Length	1-in. 1-in. 1-in. 3-in.	L_p Clear Length of Pipe Section 4.56 in. 2.50 in. 0 3.16 in.	L_{11} Length of Coupling Barrel (See Table 1) 1.94 in. 1.94 in. 1.94 in. 2.35 in.	L_s Depth of Socket 2M - N (See Table 1) 0.44 in. 0.44 in. 0.44 in. 0.83 in.
Area	1-in. 3-in.	A_p Sectional Area of Pipe (See Table 1) 0.36 in. ² 1.73 in. ²	A_{11} Sectional Area of Coupling Barrel (See Table 1) 0.82 in. ² 3.88 in. ²	A_s Sectional Area of Socket (min.) (See Table 1) $\frac{\pi}{4} (D_s^2 - G^2)$ 0.73 in. ² 3.61 in. ² B Surface Area of Bond (See Table 1) Percent Bond = 100 Percent Bond Area
Elastic Modulus (Minimum)		E_p Tensile Modulus $22 \cdot 10^6 \frac{lb}{in^2}$	E_{11} Tensile Modulus $13 \cdot 10^6 \frac{lb}{in^2}$	G Shear Modulus of Bond (Assumed) $5 \cdot 10^6 \frac{lb}{in^2}$
Flexibility	1-in. 1-in. 1-in. 3-in.	F_p Pipe Flexibility $\frac{2L_p}{E_p A_p}$ $1.15 \cdot 10^{-6} \frac{in}{lb}$ $0.63 \cdot 10^{-6} \frac{in}{lb}$ 0 $0.166 \cdot 10^{-6} \frac{in}{lb}$	F_{11} Flexibility of Coupling Barrel $\frac{L_{11}}{E_{11} A_{11}}$ $0.182 \cdot 10^{-6} \frac{in}{lb}$ $0.182 \cdot 10^{-6} \frac{in}{lb}$ $0.182 \cdot 10^{-6} \frac{in}{lb}$ $0.0465 \cdot 10^{-6} \frac{in}{lb}$	F_j Joint Flexibility (Approximate) $\frac{2L_s}{E_p A_p + E_s A_s + GB}$ $\frac{0.88}{17.41 + 6.35U} \cdot 10^{-6}$ do do $\frac{1.66}{56.1 + 51.6U}$
 <p>Clear Length of Pipe</p> <p>Coupling Barrel</p> <p>Coupling Socket</p> <p>Portion of Pipe in Socket</p> <p>Pipe Clamped within Flange at Each End of Specimen</p>				
<p>* This approximate expression includes the effects of pipe and bronze metal included within socket and should not be considered valid for values of percent bond below about 5.</p>				

TABLE 6
Approximate Relationships among Flexibilities of "Parts" of Typical Specimens

Specimen Size	Mean Percent Bond of Two Joints (U.)	Pipe		Flexibility			
		Coupling Barrel		Joint		F_{P+B+J} $\cdot 10^{-6} \frac{\text{in}}{\text{lb}}$	$\frac{F_{P+B+J}}{F}$ Percent
		$F_P \cdot 10^{-6} \frac{\text{in}}{\text{lb}}$	$\frac{F_P}{F}$ Percent	$F_B \cdot 10^{-6} \frac{\text{in}}{\text{lb}}$	$\frac{F_B}{F}$ Percent	$F_J \cdot 10^{-6} \frac{\text{in}}{\text{lb}}$	$\frac{F_J}{F}$ Percent
1-in. Diameter 11.66 in. Long	20	1.152	83.4	0.182	13.2	0.047	3.4
	40	↓	83.6	↓	13.2	0.044	3.2
	60	↓	83.7	↓	13.2	0.043	3.1
	80	↓	83.9	↓	13.3	0.039	2.8
1-in. Diameter 6.96 in. Long	20	0.631	73.4	0.182	21.2	0.047	5.5
	40	↓	73.6	↓	21.2	0.044	5.1
	60	↓	73.7	↓	21.3	0.043	5.0
	80	↓	74.1	↓	21.4	0.039	4.6
1-in. Diameter 3.96 in. Long	20	0	0	0.182	79.5	0.047	20.5
	40	↓	↓	↓	80.5	0.044	19.5
	60	↓	↓	↓	81.6	0.041	18.4
	80	↓	↓	↓	82.4	0.039	17.6
3-in. Diameter 5.67 in. Long	20	0.166	89.5	0.047	19.6	0.027	11.3
	40	↓	90.1	↓	19.6	0.024	10.1
	60	↓	90.7	↓	20.0	0.022	9.4
	80	↓	91.3	↓	20.2	0.020	8.6

ACKNOWLEDGMENTS

The writer wishes to express his gratitude to Mr. D. E. Wilcox, Piping Coordinator, Mare Island Brazing Project, for supplying the test specimens and publications and data from the Brazing Project.

This project was conceived and initiated in the Shock Branch, David Taylor Model Basin, by Messrs. R. E. Converse and H. L. Rich, to whom, and to Mr. R. L. Bort, the writer is indebted for direction, advice, and criticism.

Thanks are also due to Messrs. H. P. Hashmall, G. Junkin II, K. P. Shorrock, and P. Yarnall for performing tests, reducing data, and assisting in the preparation of the report.

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1 ORIGINATING ACTIVITY (Corporate author) Department of the Navy David Taylor Model Basin, Washington, D.C.		2a. REPORT SECURITY CLASSIFICATION
		2b. GROUP
3 REPORT TITLE STRENGTH OF SILVER-BRAZED PIPE JOINTS UNDER DYNAMIC LOAD		
4 DESCRIPTIVE NOTES (Type of report and inclusive dates) Final		
5 AUTHOR(S) (Last name, first name, initial) Zilliacus, Stephen		
6 REPORT DATE April 1965	7a. TOTAL NO. OF PAGES 29p.	7b. NO. OF REFS 7
8a. CONTRACT OR GRANT NO	8b. ORIGINATOR'S REPORT NUMBER(S) 1972	
b. PROJECT NO S-F013 10 01		
c. Task 3974	9a. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.		
10 AVAILABILITY/LIMITATION NOTICES Qualified requesters may attain copies of this report from DDC.		
11 SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY Department of the Navy Bureau of Ships, Washington, D.C.
13 ABSTRACT Destructive dynamic load tests were conducted on specimens of copper-nickel pipe joined to bronze couplings by Grade II silver-braze alloy bonds. The bond areas varied from 9 to 85 percent of the total surfaces available for bonding. Every failure occurred in the bond. Cracking of the coupling sometimes accompanied bond failure. In no case was there rupture of the pipe. Since many joint failures apparently were influenced by a coupling geometry with abrupt changes in cross section, a modified coupling design is proposed. The dynamic forces required to produce failure of silver-brazed joints having less than 40 percent bond were considerably smaller than static failure loads in tests conducted elsewhere on similar specimens. For joints with more than about 60 percent bond, the dynamic force values were of the same magnitude as the static loads. Joints having more than 60 percent bond failed only after considerable elongation of the pipe. For sufficiently great initial dynamic force, joint failure occurred immediately; otherwise two or more loadings were required. Impact velocities associated with joint failures ranged from about 1.6 to about 31 fps. It appears that the current practice of rejecting joints having less than 60 percent bond is justified for dynamic loading.		

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14. KEY WORDS		LINK A		LINK B		LINK C	
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Bronze Coupling	Tensile Stress						
Bond	Ultrasonic Inspection						
Copper-Nickel Pipe							
Joint							
Drop Test							
Ductility							
Dynamic Load							
Percent Bond							
Plastic Strain Energy							
Shock Loading							
Shear Stress							
Silver-Brazed Joints							
Static Load							
Strength							

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ENCLOSURE 1) Page 2

UNCLASSIFIED

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<p>David Taylor Model Basin. Report 1972. STRENGTH OF SILVER-BRAZED PIPE JOINTS UNDER DYNAMIC LOAD. by Stephen Zilliacus. Apr 1965. 100, 29p. illus., diagrams, graphs, tables, refs.</p> <p>UNCLASSIFIED</p> <p>Destructive dynamic load tests were conducted on specimens of copper-nickel pipe joined to bronze couplings by Grade III silver-braze alloy bonds. The bond areas varied from 9 to 50 percent of the total surfaces available for bonding. Every failure occurred in the bond. Cracking of the coupling sometimes accompanied bond failure. In no case was there rupture of the pipe. Since many joint failures apparently were influenced by a coupling geometry with abrupt changes in cross section, a modified coupling design is proposed.</p>	<p>1. Pipe-joint-strength 2. Silver brazing Effectiveness 3. Joints-Dynamic loading Test methods 4. Zilliacus, Stephen 5. S.F. 101 (1) 10, Task 3571</p>	<p>1. Pipe-joint-strength 2. Silver brazing Effectiveness 3. Joints-Dynamic loading Test methods 4. Zilliacus, Stephen 5. S.F. 101 (1) 10, Task 3571</p>
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The dynamic forces required to produce failure of silver-brazed joints having less than 40 percent bond were considerably smaller than static failure loads in tests conducted elsewhere on similar specimens. For joints with more than about 60 percent bond, the dynamic force values were of the same magnitude as the static loads.

Joints having more than 60 percent bond failed only after considerable elongation of the pipe. For sufficiently great initial dynamic force, joint failure occurred immediately; otherwise two or more loadings were required. Impact velocities associated with joint failures ranged from about 1.6 to about 31 fps.

It appears that the current practice of rejecting joints having less than 60 percent bond is justified for dynamic loading.

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